ECHNOLOGY DEPT
First Copy
PUBLIC LIBRARY
JUL 29 1942
DETROIT

Vol. X. No. 5. JUNE, 1942

THE ENGLISH ELECTRIC JOURNAL

Published by

THE ENGLISH ELECTRIC COMPANY LIMITED

The English Electric Company Limited.

Telegraphic Address:
"ENELECTICO, STAFFORD."

STAFFORD.

Telephone:
STAFFORD 700/709.

ALLIED AND ASSOCIATED COMPANIES.

ENGLISH ELECTRIC EXPORT AND TRADING COMPANY, LIMITED
THE POWER AND TRACTION FINANCE COMPANY, LIMITED
THE POWER AND TRACTION FINANCE COMPANY (POLAND), LIMITED
UTILITIES CORPORATION (POLAND), LIMITED
SUDAN LIGHT AND POWER COMPANY, LIMITED
SIEMENS BROTHERS & CO., LIMITED
SIEMENS ELECTRIC LAMPS & SUPPLIES, LIMITED
ENGLISH ELECTRIC COMPANY OF CANADA, LIMITED
ASSOCIATED BRITISH MANUFACTURERS (EGYPT), LIMITED

"ENGLISH ELECTRIC" BRANCH OFFICES IN THE UNITED KINGDOM.

Bedford ... Westminster Bank Chambers, High Street.
Belfast... ... 41, Donegall Place.
Birmingham... Central House, New Street, Birmingham, 2.
Bradford ... Thornbury.
Bristol... ... Linden Lodge, 2, Oakfield Grove, Bristol, 8
Cardiff ... 89, St. Mary Street.
Edinburgh ... Victoria Chambers, 42, Frederick Street, Edinburgh, 2.
Glasgow ... 200, St. Vincent Street, Glasgow, C.2.
Ipswich ... Westminster Bank Building, Princes Street.
London ... Queen's House, Kingsway, London, W.C.2.
Manchester ... 196, Deansgate, Manchester, 3.
Newcastle-on-Tyne Carliol House, Newcastle-on-Tyne, 1.
Sheffield ... Foster's Buildings, 22, High Street, Sheffield, 1.
Southampton... Victoria House, 23, Cumberland Place.
Stoke-on-Trent 8, Pall Mall, Hanley, Stoke-on-Trent.
Swansea ... Sketty Cross Buildings, 49, Gower Road, Swansea.
Wolverhampton Midland Chambers, Princess Street.

"ENGLISH ELECTRIC" BRANCH OFFICES, ASSOCIATES AND AGENTS ABROAD.

Australia ... SIEMENS (AUSTRALIA) PROPRIETARY, LTD., 131, York Street, Sydney and 189/191, William Street, Melbourne, C.1. Also at Adelaide and Brisbane.

Canada... ... ENGLISH ELECTRIC COMPANY OF CANADA, LTD., George Street, St. Catharines, Ontario. Also at Montreal, Toronto and Vancouver.

Central America *Supervising Representatives*:—HAYWARD & WATSON, LTD., P.O. Box 605, Marine Building, 78, Marine Square, Port-of-Spain, Trinidad, B.W.I.

Ceylon ... ... WALKER, SONS & CO., LTD., P.O. Box No. 166, Prince Street, Colombo.

Egypt ... ... ASSOCIATED BRITISH MANUFACTURERS (EGYPT), LTD., Building "B," Sharia Emad El Din, Cairo.

India ... ... THE ENGLISH ELECTRIC CO., LTD., Eruchshaw Building, Hornby Road, Bombay.
THE ENGLISH ELECTRIC CO., LTD., E5, Clive Buildings, 8, Clive Street, Calcutta.
SOUTHERN INDIA: THE ENGLISH ELECTRIC CO., LTD., CALCUTTA, represented by BINNY & CO. (MADRAS), LTD. 7, Armenian Street, Madras.

Mauritius ... *All manufactures excepting Domestic Electrical Appliances:* GENERAL ELECTRIC SUPPLY CO. OF MAURITIUS, LTD., Curepipe. *Domestic Electrical Appliances only:* ADAM & CO., Queen Street, Port Louis.

Mexico... ... H. E. BOURCHIER SUCRS., S.A., Ave. Uruguay No. 48, Mexico, D.F.

Newfoundland NEWFOUNDLAND TRACTOR & EQUIPMENT CO., LTD., P.O. Box 724, St. John's.

N. Zealand ... CORY-WRIGHT & SALMON, LTD., 31-37, Panama Street, Wellington, C.1, and Gane Buildings, Anzac Avenue, Auckland.

Portugal ... MONTEIRO GOMES, LTDA., Rua Cascais, 47 (Alcantara), Lisbon.

Portuguese E. Africa. ENGLISH ELECTRIC CO., LTD., Johannesburg, represented by P. SANTOS GIL & CIA. LTDA., Rua Consiglieri Redrosa 9, Lourenco Marques.

Rhodesia ... ENGLISH ELECTRIC CO., LTD., JOHANNESBURG, represented by RHODESIA NATIVE TIMBER CONCESSIONS LTD., Abercorn Street, P.O. Box 567, Bulawayo, S. Rhodesia, and JAGO'S AGENCIES, P.O. Box 99, N'Dola, N. Rhodesia.

S. Africa, Union of. ENGLISH ELECTRIC CO., LTD., "English Electric House," Rosettenville Road, Village Main, Johannesburg. Represented in Natal by VINCENT & PULLAR LTD., Club Arcade, Durban; in Capetown by R. G. JACK & SON (PTY.), LTD., 47-51, Burg Street, Capetown, in East London by THE CENTRAL ELECTRICAL CO., 91, Oxford Street, East London, Cape Province, and in Port Elizabeth by the AFRICAN ELECTRIC CO., 27, Queen Street, Port Elizabeth, Cape Province.

S. America ... ARGENTINA, URUGUAY, PARAGUAY: EVANS, THORNTON & CIA., S.A., Calle Defensa 465, Buenos Aires, Argentina. (Representatives in Great Britain: PARSON & CROSLAND, LTD., "Danes," Little Berkhamsted, nr. Hertford, Herts).
BRAZIL: THE ENGLISH ELECTRIC CO., LTD., represented by PARSON, CROSLAND & CIA., LTDA., Caixa Postal 1382, Edificio Commercial 1° andar, Avenida Graca Aranha No. 62, Esplanada do Castello, Rio de Janeiro.

Trinidad and Tobago. HAYWARD & WATSON, LTD., P.O. Box 605, Marine Building, 78, Marine Square, Port-of-Spain, Trinidad, B.W.I.

West Indies (British). *Supervising Representatives*:—HAYWARD & WATSON, LTD., P.O. Box 605, Marine Building, 78, Marine Square, Port-of-Spain, Trinidad.

The English Electric Journal

Vol. X. No. 5 JUNE, 1942. One Shilling

CONTENTS.

PAGE

THE PHYSICAL PROPERTIES OF MATERIALS FOR STEAM POWER PLANTS - - 121

ELECTRIFICATION OF THE BLOOMING AND RAIL MILLS IN AN AUSTRALIAN STEEL WORKS - - - - - - 127

SOUTHERN RAILWAY LOCOMOTIVE FOR UNIVERSAL OPERATION - - - 131

All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

Our readers will note that in this issue the now familiar outer cover and advertisement supplement which have been a feature of the Journal for the past twenty years have been dispensed with. This has been necessitated by the ever increasing exigencies of paper rationing and our desire to give the maximum number of technical articles in each issue within the limits of the paper made available.

The development of the modern steam turbine to its present state of high efficiency owes much to metallurgical research carried out both by metallurgists and turbine designers. In the first article in this issue Mr. F. J. Cowlin discusses some of the physical properties of materials used in the construction of steam turbines with particular reference to the effect of high temperatures and prolonged stresses on those materials. The article goes on to discuss some of the limitations governing long-time creep tests and illustrations of the equipment used for such tests are included. The Author then briefly describes the photo-elastic method of stress analysis, and interesting coloured illustrations are reproduced which show photo-elastic tests on turbine blade roots.

The next article describes the conversion to electrical drive of an important steel works in Australia. The equipment supplied by the Company included a Blooming Mill Motor of 21,000 (peak) H.P., and a Rail Mill Motor of 19,000 (peak) H.P., together with the Ilgner Convertor equipment and Control Gear for each of the motors. A notable feature was the rapidity with which the changeover from steam to electric drive was carried out.

The concluding article gives brief particulars of a new and very interesting electric locomotive which recently has successfully completed its technical trials on the Southern Railway. This locomotive is equally suitable for hauling heavy goods or fast passenger trains. The electrical equipment of the locomotive incorporates a special feature in its design which enables it to continue to exert a drawbar pull when passing over gaps in the conductor rail at junctions and crossings.

The Physical Properties of Materials for Steam Power Plants.

By F. J. COWLIN, A.M.I.Mech.E., A.M.I.Mar.E.

(Abstract from the Presidential Address to the Rugby Engineering Society, 1941-42.)

Among the most important considerations with which an engineer has to deal are the properties of the materials which are available for his particular purpose, and the rapid developments which have taken place in connection with steam power plants during the last 20 or 30 years have led to rather different conceptions of the nature of these properties from those previously held.

It is the object of this article briefly to review some of these changes in the light of present knowledge so that the position will be clarified and a truer perspective obtained of the path along which future work and research might proceed.

It is well known that the efficiency of any heat engine is controlled by the ratio between the temperature at which heat is taken in, and that at which it is rejected, and it is the persistent aim of the power plant engineer in his quest for higher efficiency to lower the temperature of heat rejection and increase the temperature of heat reception. In the case of the steam cycle under consideration, the temperature at which heat is rejected is that of the condenser circulating water, which is dependent upon site conditions and cannot be varied at will.

The temperature at which heat is received into the cycle can, however, be fixed arbitrarily by adjusting the boiler conditions, and the development of the steam cycle has consequently been accompanied by continual increases of the total initial steam temperature.

These increases in temperature have led to a marked change in the attitude of the engineer to the available materials of construction, particularly where they are subjected to the maximum steam temperature as in the boiler superheater, the steam piping, and the steam inlet portions of the steam turbine.

The materials normally employed for these parts with temperatures up to, say, 700 degs. F. are cast or forged carbon steels, and as long as temperatures did not exceed this limit, the criteria employed for determining the permissible stress under working conditions were the physical properties of the materials at room temperature. The working stress was variously fixed at some fraction of the breaking strength of the material, its so-called yield point or the limit of proportionality.

The values of these physical properties based on short-time tests, however, vary considerably as the temperature rises, and Fig. 1 shows typical variations of the principal properties plotted on a temperature base. It will be noticed how rapidly the ultimate strength falls away above certain temperatures.

A further property of great importance since it affects the stiffness of a structure, namely, the Modulus of Elasticity, also varies appreciably with temperature as shown in Fig. 2, and in steam turbine practice this variation must be taken into account in determining the critical speeds of the turbine rotors.

In the higher temperature ranges, however, the above properties do not truly disclose the probable breaking strength of a material in service since it has long been known that a test piece which will

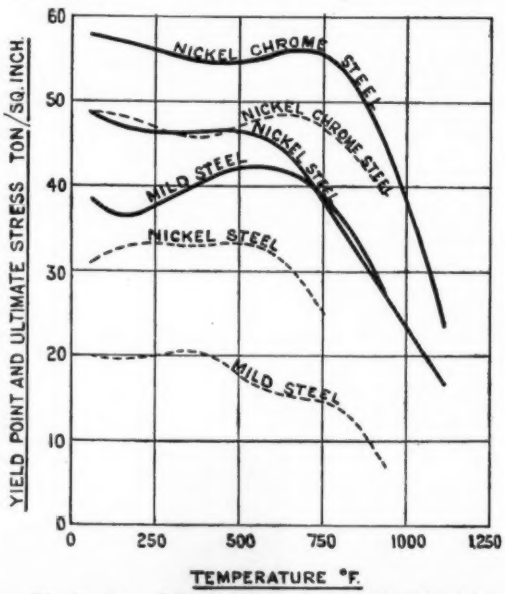


Fig. 1.—Curves showing properties of steel at elevated temperatures. (Full line = ultimate tensile strength; dotted line = yield point.)

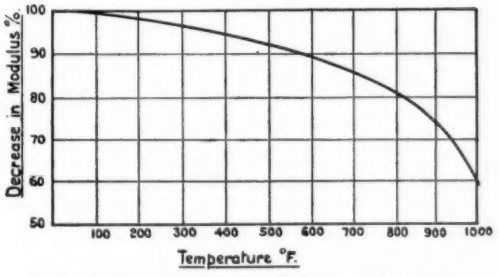


Fig. 2.—Variation in modulus of elasticity with temperature for steel.

sustain a certain load for a few minutes will fail under a much lower load if this is maintained for a longer period.

The physical process causing this failure is a slow deformation or flow of the metal now referred to as "creep," and its effect becomes more and more important as the temperature rises, until under certain conditions it becomes the predominating consideration. The general nature of the phenomenon is well illustrated by Fig. 3, which shows an ideal schematic family of curves suggested by MacVetty to represent the way in which total deformation would vary with time were the results of very long-time tests available. Long-time tests in this sense mean tests of 100,000 or even 200,000 hours duration, or in other words, tests lasting from 10 to 20 years.

The curves can be assumed to show from bottom to top increasing increments of stress at any fixed temperature or equally well increasing temperatures at any one load.

It will be seen from the curves that the total deformation may be divided broadly into four stages, the first of which is the elastic deformation occurring as soon as load is applied. Stage 2 is characterised by a rapid rate of increase of deformation which decreases with time until in Stage 3 a uniform rate is attained. This in the fourth or last stage is succeeded by a rising rate which, if allowed to continue, will lead to excessive deformation and ultimate failure.

The designer is consequently faced with a four-dimensional relationship between stress, temperature, total deformation and time, and the question immediately arises as to whether there is a limiting stress-temperature, relation below which deformation or creep does not increase with time. As far as the author is aware no definite answer can yet be given to this question, and in an attempt to supply one, Dr. Hatfield of the Brown-Firth Laboratories, has put in hand an interesting experiment.

A strip of cold-worked austenitic steel was put under test in 1929 under a stress of 25 tons/sq. in. In 1939 or ten years later it was reported that no extension on an 8 in. gauge length could be detected although the measuring apparatus was capable of detecting extensions of 1/40,000 of an inch. This means that if creep is proceeding is is doing so at a rate of less than 4×10^{-11} inches per inch per hour.

Whatever the final results of this experiment, which will be of considerable academic interest, it can be said quite definitely that the stresses imposed on materials subjected to the higher steam temperatures now commonly used must be kept below certain limits to ensure that the total deformation occurring during the life of the part in question is kept within the permissible limits fixed by its particular purpose or duty.

Steam turbine engineers usually demand that turbine discs shall not stretch more than 0·1 per cent. during a life of 100,000 hours, and this is equivalent to a creep rate of one hundredth of one millionth of an inch or 10^{-8} inches per inch per hour. On the other hand, much greater deformations can be allowed on steam piping or boiler tubes and a usual figure for these items is ten times the above or 10^{-7} inches per inch per hour. In both cases these figures are based on the assumption that the rate of creep remains constant during the life of the plant.

The problem of selecting suitable materials to withstand predetermined stresses at particular temperatures with these very small deformations requires great care. It is not surprising, therefore, that notwithstanding the vast amount of experimental work which has been carried out during recent years on the creep properties of materials, particularly ferrous alloys, much of which has

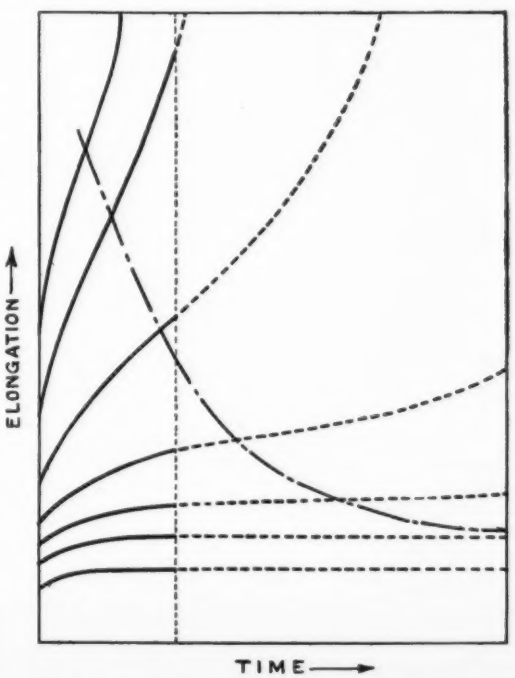


Fig. 3.—Schematic Creep Curves (MacVetty).

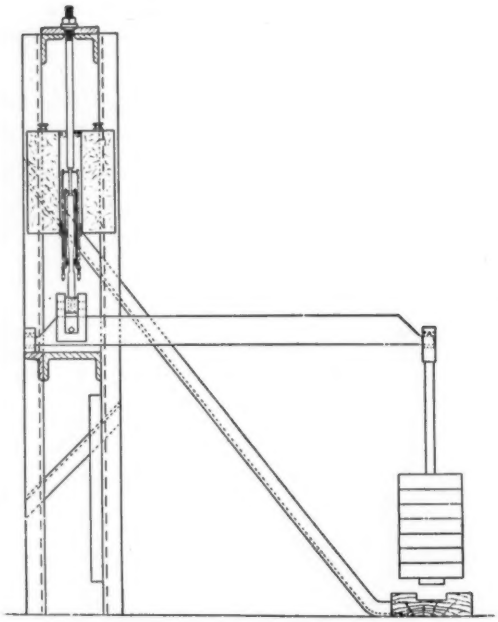


Fig. 4.—Diagram of Creep Testing Unit.
(Reproduced by courtesy of the Director, National Physical Laboratory. Crown copyright reserved.)

been described in a vast and growing literature on the subject, the reliable information available is exceedingly scanty. It might consequently be of interest to consider some of the principal reasons for this position.

In the first place the total deformation to be measured is extremely small, a 0·1 per cent. deformation being only about half of the 0·2 per cent. permanent deformation usually employed in room temperature tests of the yield point. The thermal expansions of steel compared with creep deformations are very great. Further, the tests to be reliable must be carried out over long periods with the test-piece maintained at a high temperature, and this temperature must be kept constant within very close limits. An increase in temperature of 1° F. may increase the creep rate by 10 per cent., or in other words, a rise of 10° F. may halve the service life as deduced from such tests.

Under these conditions it will be appreciated that elaborate testing equipment is essential and Fig. 4 shows a diagram of a creep testing unit used at the National Physical Laboratory for tensile tests. The specimen is loaded by means of the lever and weights shown, and kept at constant temperature by means of an automatically controlled electric furnace surrounding it. Extremely accurate optical apparatus is used to measure the very small deformations already referred to.

In view of the time factor involved, the compilation of data by the use of only one such machine is exceedingly slow, and Fig. 5 shows the batteries of creep machines now installed at the N.P.L. for creep testing purposes.

This laboratory, which is 50 ft. square, has double walls and windows and is maintained at 72° F. with a maximum variation above or below this temperature of $1\frac{1}{2}$° F.

Fourteen of the forty tensile testing machines measure to 10^{-6} strain and others to 10^{-5} or 10^{-4} strain.

Creep relaxation machines and equipment for the study of creep under combined tension and torsion are also available.

The difficulties of maintaining and operating a large number of machines has been overcome by MacVetty in the U.S.A. by the production of a single test plant in which twelve test bars can be used simultaneously, each bar comprising five test pieces so that sixty tests at any given temperature may be carried out simultaneously. A sectional arrangement of this unit is shown in Fig. 6, and an illustration of one of the six units installed by the Westinghouse Co. in their Pittsburgh Laboratory is reproduced in Fig. 7.

The general lay-out of this laboratory is clearly illustrated in Fig. 8, from which it will be clear that the provision and maintenance of a laboratory for creep testing involves considerable

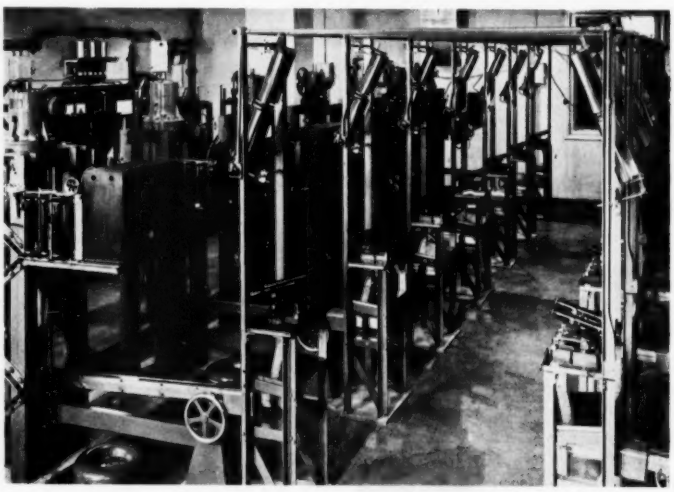


Fig. 5.—Batteries of Creep Testing Machines at the National Physical Laboratory.
(Reproduced by courtesy of the Director, National Physical Laboratory. Crown copyright reserved.)

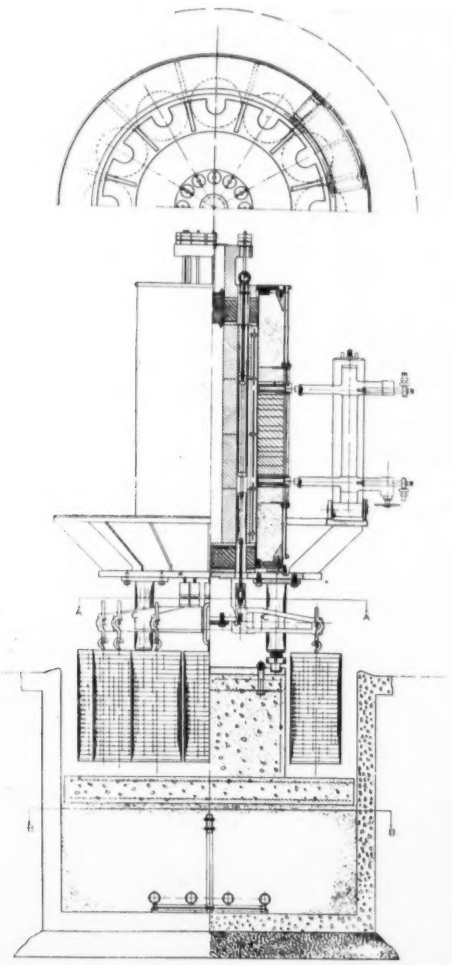


Fig. 6.—Sectional Arrangement of Multiple Creep Testing Machines.
(Reproduced by courtesy of the Westinghouse Electric and Manufacturing Company.)

financial commitments.

A further difficulty encountered during creep testing has been that specimens of material having the same chemical analysis have been found to possess materially different creep rates. It is now considered that this is due to varying metallurgical structures, such as grain size, but the laws connecting grain structure and creep properties are far from clear and are still under investigation. There is also evidence to show that at the temperatures under consideration the structure of the material changes with time and so affects the creep properties of the original material.

Whilst this remains the position as far as straight carbon steels are concerned, it is not surprising that the effect of alloying elements is still in dispute. Knowledge on this aspect of the subject is still scanty although sufficient evidence has been collected to show that the effect of molybdenum, and to a lesser extent tungsten and vanadium, is so powerful that it swamps all other variables and makes itself evident.

The improved creep properties of alloy steels are, however, subject to the further consideration that all these steels tend to fail by intercrystalline cracking at much lower elongations than a plain carbon steel. For instance, microscopic laboratory tests have detected intercrystalline cracking in the very commonly used 0·5 per cent. molybdenum steel with elongations between 1 per cent. and 2 per cent., so that it would be unsafe in practice to use this class of steel if, during the life of the plant, the total deformation exceeded a fraction of this figure. A plain carbon steel could safely be used with ten times the deformation allowed on an alloy steel were this possible from a dimensional standpoint.

The mass of data on creep already published has been mentioned and one of the difficulties of co-ordinating this is the varying technique employed in testing. The bulk of the German and Russian work has been based on accelerated tests and cannot be reconciled with the long-time testing carried on by some twelve American laboratories and three or four in this country. It appears that useful co-relation could be enhanced by the establishment of a universal testing code, such as that tried out by the Joint Committee of the A.S.T.M. and A.S.M.E.

Fig. 7.—Multiple Creep Testing Machine installed at the Pittsburgh Laboratory of the Westinghouse Company.
(Reproduced by courtesy of the Westinghouse Electric and Manufacturing Company.)

Fig. 8.—Creep Testing Laboratory.
(Reproduced by courtesy of the Westinghouse Electric and Manufacturing Company.)

The difficulties associated with long-time creep testing have led to the introduction of various short-time tests, but just as there is no co-relation between long-time creep tests and short-time high-temperature tensile tests, so short-time tests such as the Hatfield " time yield " test, or the Bar-Bardgett test cannot give the final creep data required. This, however, does not imply that such tests are not valuable, as it would appear that once a steel has been produced having definite creep resistance characteristics, the short-time tests would be extremely useful in identifying steels having the same characteristics, provided their manufacturing history and heat treatment had been held closely to that of the original sample.

All the tests so far referred to have been simple tensile tests and it is possible that torsion or shear tests might possess advantages but the technique of such tests is not yet on a sure footing, and the indications are that they will be no less tedious and expensive.

Before leaving the subject a further matter which principally concerns the designer, may be referred to.

During the course of years a system of analytically predetermining the stresses on machinery parts has been built up, the whole or parts of which are familiar to all engineers. This system is based on the assumption that the materials used are perfectly homogeneous and elastic, and that, in consequence, the distribution of stress throughout a member may be determined. Now it has been shown that under creep conditions the material actually flows, and so to a certain extent loses its assumed properties of elasticity with the result that the distribution of stresses previously assumed no longer holds and to enable the designer to handle his materials with the same confidence as before, it will be necessary to build up a modified theory, taking this new factor into account.

Most engineering structures are, however, subjected to compound stresses and this complicates the issue since practically no experimental data is available to enable the effect of creep under compound stress to be determined. In building up any modified theory it is therefore necessary at present to rely only on existing data relating to tensile stress and to premise relations between this condition and the conditions under compound stress.

Fortunately a little consideration will show that the normal effect of creep is to produce a redistribution of stress throughout a member in a more uniform manner than would occur under the elastic theory and so reduce the value of the maximum stress calculated on the latter basis.

The effect will be clearly seen from Fig. 9, which shows the estimated values of the tangential and radial stresses in a turbine wheel. The full line curves show the stresses calculated on the usual elastic theory and the dotted lines the corresponding stresses calculated on a modified theory based on existing creep test data.

It will be seen from the foregoing remarks, brief as they have been, that what is in effect a new field of engineering science has been opened up which will provide scope for the combined work of chemists, metallurgists, steel makers and

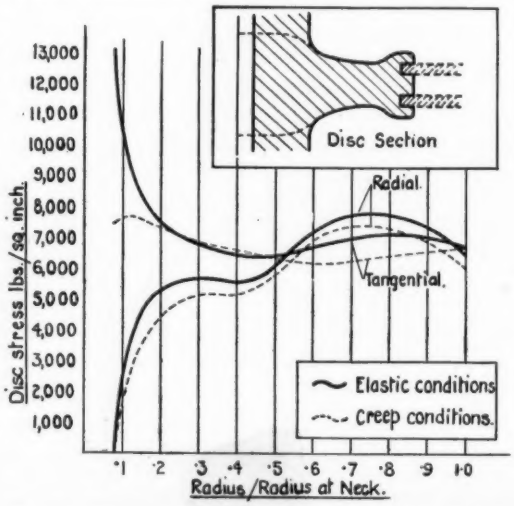


Fig. 9.—Curves showing stresses in Turbine Disc under elastic and creep conditions.

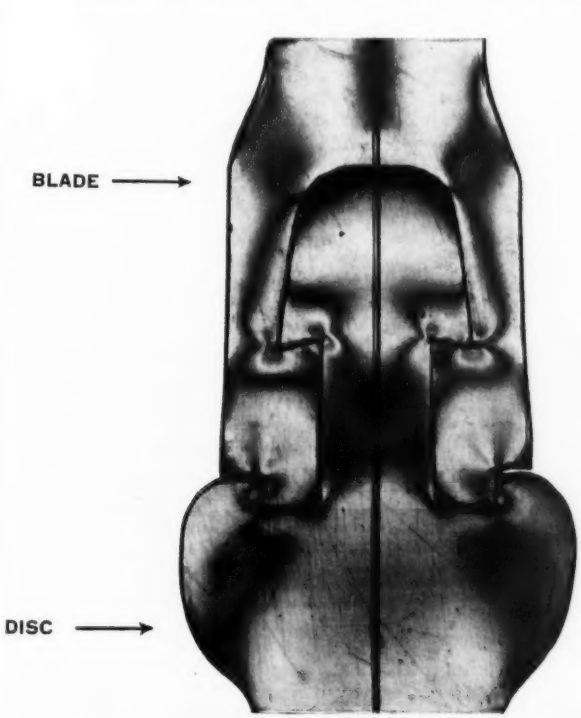
engineers for some considerable period before a completely satisfactory position is reached on our knowledge of the behaviour of metals under creep conditions. The present position, where extrapolation from tests of from 1,000 to 3,000 hours have to be carried out tenfold to service lives of 100,000 hours or longer, leaves much to be desired, but is at present the only method open to workers in this interesting and useful field.

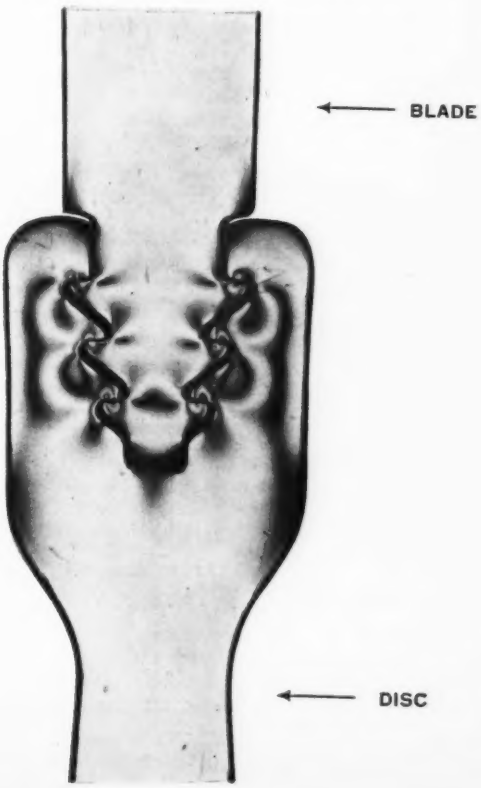
The foregoing very brief review of the state of our knowledge regarding the behaviour of metals at high temperature and of our available methods of determining the working stresses under creep conditions leads naturally to some similar considerations relating to metals at ordinary temperatures.

One of an engineer's primary problems when designing any new type or size of machine is to determine not only the magnitude of the maximum stress which will be imposed on its various members, but the distribution of stress throughout that member. The present methods of analytical investigation, whilst being indispensable, fall lamentably short of the engineer's requirements in the latter respect. An example of this kind is provided by a problem which has to be solved by all turbine designers, namely, the method by which the turbine blading shall be secured to the revolving wheels. The development of the steam turbine has been accompanied by the introduction of a large number of different types of blade fixing, the primary object of which has been to utilise the material of the blade root and wheel head to the maximum advantage and so produce a connection of ample strength and at the same time relieve the superimposed blade load on the wheels. These blade root constructions do not lend themselves to stress analysis by the usual analytical methods, but the photo-elastic method is particularly applicable, and Figs. 10 and 11, prepared from a test made in the Company's Turbine Research Department, provide interesting examples of the additional information which it is possible to obtain by this method.

The technicalities of photo-elastic phenomena are too involved to be dealt with in this brief reference to the subject, but the following short explanation of the method used may be of interest.

In 1816 Sir David Brewster discovered that when a transparent isotropic material is stressed it becomes doubly refracting so that when examined by polarised light with a suitable optical arrangement, colour effects are seen, the effects at any one point being dependent on the





Figs. 10 and 11.—Photo-elastic Tests on Turbine Blade Roots.

stress at that point. Sir David himself used glass, but in recent times when materials such as celluloid, resin compounds, etc., which can be readily manipulated, became available, the study of stress distribution by photo-elastic methods has been highly developed, notably by Professor Coker.

If a specimen of a transparent isotropic material is stressed, then the stresses in any plane perpendicular to the direction of light may be resolved into two principal stresses at right-angles to each other. Plane-polarised light falling on the specimen is resolved into two components, polarized in the directions of the principal stresses.

Each of these component waves is retarded in passing through the specimen, the actual retardation being proportional to the stress, so that there is a relative retardation between the waves emerging from the specimen which is proportional to the difference between the principal stresses. It is the interference occasioned by the relative retardations mentioned which produces the colour effects.

A stressed specimen under examination by plane-polarised light will thus show a series of colour bands or isochromatic lines. At any point on any one band the difference between the two principal stresses will be the same, increasing values of this quantity being from red through the spectrum to blue.

A second effect is the production of dark bands or patches called isoclinic lines, which are useful in determining the directions of the principal stresses at any point.

With suitable refinements in method and measuring instruments, it is possible to obtain quantitative results as far as the specimen is concerned, but how far this is useful in practice depends upon the degree to which the specimen reproduces the actual problem under consideration.

It will be clear, however, that the information regarding stress distribution throughout a loaded structure which can be obtained by this method provides a useful addition to that provided by ordinary analytical methods.

In this short article it has not been possible to deal with a number of other important factors which influence the choice of materials for power plant construction. At high temperatures, for instance, most steels are subjected to an oxidation or scaling process when exposed to high pressure steam or furnace gases, and the choice of alloying elements is governed to a certain extent by this phenomenon as well as their effect upon the increase in creep strength.

Again, fatigue plays an increasingly important role in determining the stresses which may be imposed on a number of a power plant's components, particularly the portions of the prime movers which rotate at high speeds and are consequently subjected to reversals of stress at high frequencies. This aspect of the subject is now well understood following the lengthy researches of Wohler, Reynolds and Smith, Stanton and Bairstow, and subsequent investigators, some of whose work dates back to the end of the 19th century. Failure by fatigue, however, becomes increasingly important with high speed machinery and particularly where vibrating conditions arise which may produce resonance phenomena in various parts.

Although the foregoing remarks have been primarily concerned with materials used for steam power plants, they are equally applicable to materials used for other purposes under relevant conditions, and show how necessary it is for the Engineer to be well informed regarding the results of modern physical and metallurgical research, if consistent reliability is to be maintained under the more stringent conditions imposed on most present-day machinery.

Electrification of the Blooming and Rail Mills in an Australian Steel Works.

(Abstract from the B.H.P. Review of an article by A. H. Kinley, Chief Electrical Engineer at a steel works of The Broken Hill Proprietary Company, Limited, where the plant he describes is installed.)

BLOOMING MILL.

Type of Drive.

The blooming mill is a two-high reversing mill having 36 in. pinions, and was originally driven by a 42 in. × 60 in. twin-cylinder horizontal non-condensing back-geared reversing mill engine, working from a maximum steam pressure of 160 lbs. per square inch.

As it is proposed to increase the mill from a 35 in. × 80 in. to a 40 in. × 96 in. mill at a later stage, electrical drive equipment suitable for a 40 in. mill is installed.

The blooming mill—the most important steel works' mill—performs the first stage of the rolling process in that it rolls the original ingots received from the open hearth department, via the soaking pits, into blooms or plate slabs of suitable size for re-rolling by the smaller mills into finished products.

A reversing mill of this description requires a driving unit that will run at a low entry speed, accelerate quickly to any speed within its range,

de-celerate in the minimum time to the best exit speed and rapidly reverse ready for the next pass.

When it is considered that the total weight of the rotating parts of the mill and motor is approximately 212 tons, and this weight has to be accelerated, de-celerated and reversed thirteen times a minute, and in the thirteen passes roll a length of 210 ft. of steel in breaking down a 23 in. × 20 in. × 6 ft. 8 in. ingot to a 9 in. × 8 in. × 35 ft. 6 in. bloom, some idea is obtained of the horse-power needed and the degree of speed control required.

The Ilgner system, which is used very widely for the electrical drive of reversing mills, was adopted and details of the actual units installed in the motor room are given below.

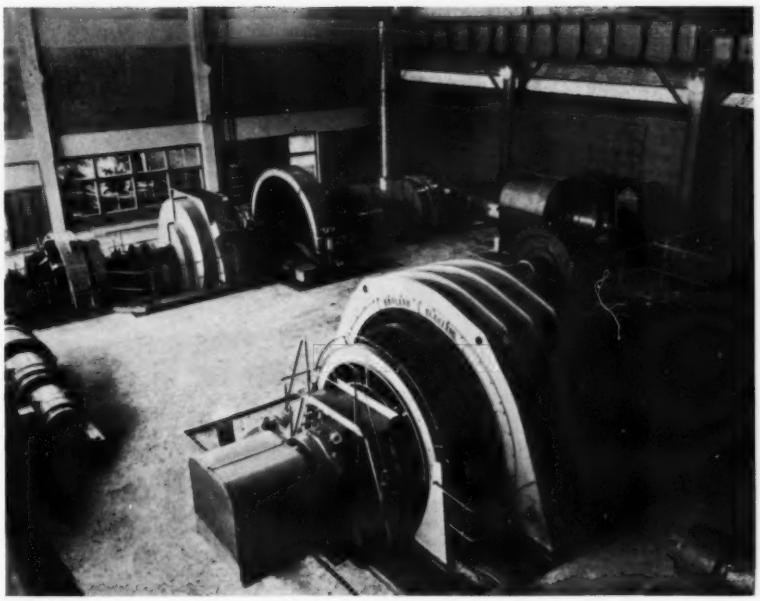


Fig. 1.—Blooming Mill Motor Room, showing in foreground Main Mill Motor—part of Motor Generator in background and section of Exciter Set (left) and Circulating Fan on right.

Main Mill Motor.

The blooming mill main mill motor is a 7,000 H.P. 1,300-volt reversing direct current motor, arranged for Ward Leonard control up to a base speed of 50 r.p.m., and for field weakening control up to 120 r.p.m.

The total weight of the motor is 190 tons.

Owing to the low speed of rotation and the frequent reversal, the usual oil rings cannot be relied upon, so forced lubrication is adopted. When uncoupled from the mill and with the oil pressure on the bearings the 79-ton armature can be turned by hand.

Adequate ventilation of the motor is another difficulty introduced due to the low speed and reversing requirements. Forced ventilation by means of booster fans is provided to take away the heat generated in the motor windings.

The motor is direct-coupled to the rolls through the pinion housing, and is capable of exerting a momentary peak of 21,000 H.P. Fig. 1 illustrates the motor erected in the motor room.

Flywheel Motor Generator Set.

To convert the Works 6,600-volt, 3-phase, 25 cycles alternating current supply to the direct current supply required by the main mill motor, a 6-unit, 445/495 r.p.m. motor-generator set is installed. This motor-generator set consists of four 1,500 kW. 650-volt direct current generators, direct-coupled to a 5,000 H.P. slipring induction motor, and a 14 ft. diameter, 50-ton flywheel having a stored energy of 200,000 H.P.-seconds to equalise the load on the power house. The motor-generator set weighs 155 tons, and has an overall length of 64 ft.

Fig. 2 shows the rail mill flywheel motor-generator set which, with the exception of the flywheel, is a duplicate set.

Stator Control Cubicle and Liquid Slip Regulator.

The power supply to the 5,000 H.P. motor of the motor-generator set is taken through the stator control and metering cubicle, which houses all the necessary instruments and regulator control devices. A liquid slip regulator is installed to control the speed of the motor.

This portion of the equipment, together with the flywheel, gives the Ilgner control—the principle being that when the load of the motor-generator set motor exceeds the setting of the regulator control device, the regulator operates in a direction to lower the speed of the motor generator set. In falling to this lower speed, the flywheel gives out its stored energy and takes the balance of the load.

Thus, with a regulator setting of 5,000 H.P. and a 20,000 H.P. peak load on the main mill motor, the flywheel would release 15,000 H.P. for a short time, and only 5,000 H.P. would be drawn from the power house. The energy is automatically restored in the flywheel between passes.

Fig. 2.—Rail Mill Motor Room, showing Motor-Generator Set in background and Exciter Set in foreground.

Exciter Sets and Control Cubicles.

A smaller but a very important unit is the exciter set. This set consists of a 440-volt squirrel-cage motor driving three direct-coupled exciters. These small exciters are in effect small direct current generators, the fields of which are controlled by the mill driver while the armatures supply the field currents of the main mill motor and the four generators. By this means the control of machines totalling 40,000 H.P. is brought to a single lever, operating a controller which, although only handling a maximum of 24 amperes, controls a load of 13,000 amperes.

The actual operation of the controller (which is located in the mill pulpit) is quite simple, as the speed of the motor follows the position of the lever, i.e., the lever right forward gives full speed in a forward direction, the middle position is zero speed, and the lever pulled back gives speed in the reverse direction.

A set of instruments indicating the speed and load on the mill motor is located in the mill pulpit for the guidance of operators.

Fig. 2 shows the exciter set for the rail mill motor room. The blooming mill exciter set is similar to this set.

RAIL MILL.

Type of Drive.

The rail mill is a three-high mill, having 30 in. pinions, and was originally driven by a 42 in. × 60 in. twin-cylinder horizontal non-condensing direct-connected mill engine, working at a maximum steam pressure of 160 lbs. per square inch.

The rail mill rolls the blooms received from the blooming mill into billets or sheet bar slabs for the 18 in. continuous billet and sheet bar mill, or into shapes or sections of relatively heavy weight per foot.

A three-high mill of this type requires a driving unit similar to that described for the blooming mill, with the exception that it does not normally reverse. However, provision for reversing under emergency conditions is provided.

As the steel (i.e., the bloom) entering the rail mill is of smaller cross sectional area, but of longer length, than the ingots entering the blooming mill, a higher roll speed is required in the former than in the latter.

The electrical equipment for the main drive of the rail mill is similar to that of the blooming mill, i.e., the Ilgner system is used, but the main mill motor is of slightly smaller horse-power and has a higher speed.

Main Mill Motor.

The rail mill main mill motor is a 6,700 H.P., 1,300-volt, direct current motor, arranged for Ward Leonard control up to a base speed of 82·5 r.p.m. and for speed control by field weakening up to 160 r.p.m.

The total weight of the motor is 134 tons. Forced lubrication and ventilation are also provided on this motor.

The motor is direct-coupled to the rolls through the pinion housing, and is capable of exerting a momentary peak of 19,100 H.P.

The flywheel motor-generator set, with the exception of the flywheel, which has a stored energy capacity of 120,000 H.P.-seconds, is a duplicate of the blooming mill set.

The stator control cubicle and liquid slip regulator, the exciter set and control cubicles are essentially similar to those installed in the blooming mill motor room.

High-Tension Switchboards.

The incoming 6,600-volt electric power supply from the power house to each motor room is fed through a metalclad H.T. switchboard to the various high-tension units in the motor room. This switchboard is of the horizontal drawout type, and incorporates busbars.

Low-Tension Supply.

To provide a low-tension 440-volt supply for the motors driving motor room auxiliaries, a 500 kVA. transformer is provided for each motor

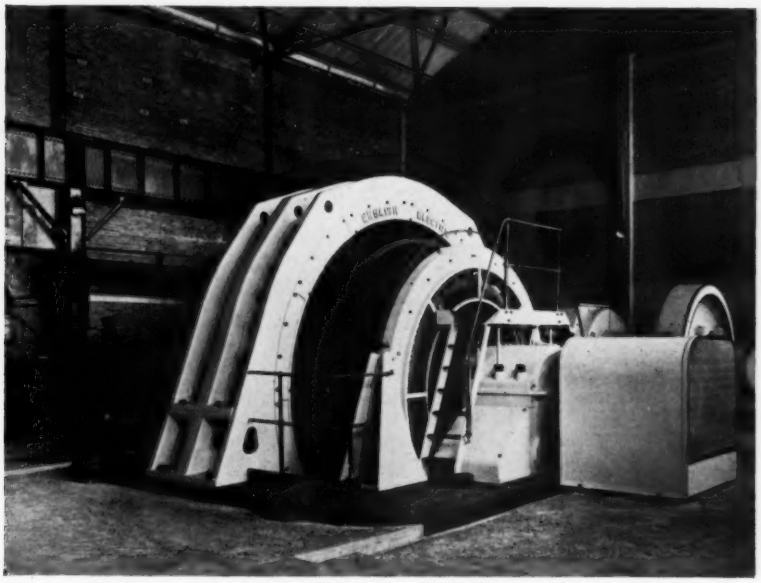


Fig. 3.—Rail Mill main Mill Motor erected in motor room.

room. Both transformers are installed in an outdoor structure adjacent to the blooming mill motor room.

Enclosed-type low-tension switchboards are installed in each motor room, and provide power for the exciter set, air booster fans for the mill-motor, air-circulating fans, make-up air fans, mill-motor oil pumps, oil pumps for flywheel and motor-generator set.

Ventilation of Motor Rooms.

Dust and high temperatures are enemies of all electrical equipment. A steel works atmosphere contains a large proportion of metallic dust which is injurious to the insulation of the machines.

In order to eliminate as much dust as possible, a circulating system incorporating air coolers was adopted. In this system, the cooled air from the motor room basement is drawn into the pits, under the machines, and forced through the machines into the motor room, absorbing the heat from the machines during its passage through them. Circulating fans mounted in the motor room floor then draw the hot air from the motor room and force it through air coolers into the basement, reducing it to the desired temperature.

The advantage of this system is that only a small percentage of air—called the " make-up air "—is drawn from outside the motor room. This " make-up air," which is required to make up air leakages from the system and to keep the air fresh, is drawn through automatic viscous-type air filters by the " make-up air " fans.

Another advantage of the system is that the motor room is maintained at a slightly higher pressure than the outside atmospheric air, and this tends to prevent the entry of dust.

Blooming Mill Construction.

To avoid any delay in changeover to electric drive, the blooming mill motor was located outside the steam engine foundations,and all other motor room equipment located in positions enabling them to be installed with the steam drive in operation.

With the exception of the mill motor armature, which was received by rail on July 24, 1939, the remainder of the first shipment was received at the Steel Works on July 22, and transferred to railway trucks for transport to the motor room. The heavier lifts were off-loaded from the trucks directly into the partially completed motor room. The last shipment containing the control cubicles was received on August 24.

The steam drive was shut down at midnight on September 3, and the installation of the connecting shaft was proceeded with immediately. The mill started up with electric drive at 11 a.m. on September 4, a changeover time of only 11 hours.

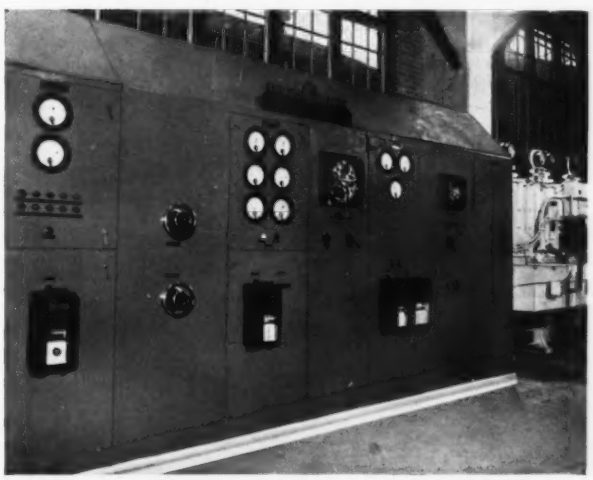


Fig. 4.—Generator and Motor control cubicle.

Rail Mill Construction.

All the electrical equipment was located in positions enabling it to be installed with the steam drive in operation. Owing to a portion of the steam engine having to be dismantled and the foundations altered to take the intermediate bearing on the connecting shaft, a longer changeover period was necessary for this mill. The erection of the electrical equipment was completed before any favourable opportunity for the actual changeover arose.

The steam drive was shut down at 8 a.m. on Sunday, December 24, and the mill started up on electric drive at 4 p.m. on Wednesday, December 27, 1939.

Southern Railway Locomotive for Universal Operation.

The illustrations reproduced in Figs. 1 and 2 show the general appearance of the first of these locomotives, which has now successfully completed its technical trials on the Southern Railway, and we give below some preliminary information about this interesting unit.

It is capable of hauling heavy goods or fast passenger trains when supplied with power from a third rail at 600 to 660 volts direct-current. On goods service the locomotive will accelerate a train of 1,000-tons at 0·3 miles-per-hour-per second and attain a balancing speed of 33 miles-per-hour on a level track. In passenger service, with a train of 420-tons, the acceleration is 0.48 mph. per second and the balancing speed 61.5 mph.

The general particulars are as follows :—

Type	C.C.
Weight	99.55 tons.
Length over buffers	56 ft. 9 in.
Total horse-power	1,710
Maximum safe speed	75 mph.
Maximum tractive effort ...	45,000-lbs.

The locomotive embodies many new and novel features, one of these being the method of control of the traction motors. Control is of the dynamic type, that is, by rotating machines instead of the usual series resistances, and all combinations of speed and tractive effort are obtainable by bucking or boosting the voltage in the traction motor circuits. For this purpose motor-booster sets are provided and so arranged that on starting the train practically zero volts exist across the traction motors and smooth notching up to full-speed is available. When running at full-speed the voltage applied to the motors is boosted to almost double the supply voltage. Thus, the three motors in series on each circuit can operate efficiently on any voltage up to 1,200 and meet all demands ranging from large tractive effort to high speed.

The master controllers in the two driving cabs operate on the fields of the boosters and progression from start to full-speed is made through 26-notches, each one being a running notch and capable of continuous use.

To provide the different characteristics required for fast passenger service and heavy goods the motors are designed with a wide range of field

Fig. 1.—The Southern Railway passenger and freight traffic electric locomotive C.C.1.

Fig. 2.—The locomotive running technical trials on a 14-coach semi-fast passenger train.

control. For the heavy traffic they operate with full-field characteristic and for fast passenger running the field can be weakened by means of a field control switch.

The rotating machines which are used for this control are fitted with flywheels to augment the store of kinetic energy, and this energy is available to maintain current in the motor circuits and their tractive effort during short interruptions to the supply. In service short interruptions to the power supply to the locomotive are frequent, due to the gaps in the third-rail system. These gaps, which exist at crossings and cross-overs, are in many places too long to be spanned by the collector shoes of a locomotive. The kinetic energy of the flywheel sets can also be utilised in the event of a locomotive being stopped in a gap, and under these conditions the driver can start the train by utilising the flywheel energy which is sufficient to move the heaviest train out of the longest gap. The motors of these sets are supplied with current from the line and arranged to start up automatically by a push-button located on the control desk of each driving cab.

The six traction motors, mounted three on each bogie, are of standard type, nose-suspended and axle-hung, with single-reduction gears, and are force-ventilated by fans coupled to the motor-booster sets.

Current is collected from the live rails by four pairs of collector shoes in parallel and delivered to the traction motors through the motor booster sets. In addition, a pantograph is provided to enable the locomotive to undertake shunting duties in sidings fitted with overhead contact wires.

The complete locomotive was designed to meet the specification of Mr. Alfred Raworth, M.Inst.C.E., Chief Electrical Engineer of the Southern Railway, and the electrical equipment was built at one of The English Electric Company's Works. The mechanical portions of the locomotive were built by Mr. O. V. Bulleid, M.I.Mech.E., Chief Mechanical Engineer of the Southern Railway, in the Company's Ashford Works.

THE PRODUCTS OF THE ENGLISH ELECTRIC COMPANY LIMITED

DISTINGUISHED BY SERVICE

GENERATING PLANT FOR STEAM, WATER OR OIL POWER

Complete Power Stations of any size. Steam Turbines and Turbo-alternators. Surface Condensers. Horizontal and Vertical Water Turbines and Alternators. Diesel and Fullagar Oil Engines. Alternators and D.C. Generators for all forms of drive. High-tension D.C. Generators for Radio Transmitting Stations.

ELECTRIC TRACTION AND TRANSPORT

Complete Electric Traction Systems. Electric Locomotives. Electric Motor-coach stock. Diesel-electric and Diesel-mechanical stock. Motors and Control Equipment for Railway or Road Vehicles. Battery Locomotives. Industrial Locomotives for all services. Rail Cars. Electric Tramcars. Electric Trolleybuses. Tramcar Bodies and Trucks. Bodies for Trolleybuses, Omnibuses and Coaches.

ELECTRICAL EQUIPMENT FOR MARINE PURPOSES

Diesel-electric and Turbo-electric Equipments for ship propulsion. Diesel-electric and Turbo-electric Generating Sets for ship's auxiliaries. Motors for auxiliary drives.

TRANSMISSION SYSTEMS, SWITCHGEAR AND CONTROL

Complete Indoor or Outdoor Switching Stations. Oil Circuit-breakers of highest breaking-capacities. De-ion Grid Contacts for Arc Control. Metalclad Switchgear. High-rupturing-capacity Fuse Units. Transformers of any output, voltage and type. Booster Transformers. Induction Regulators. Arc Suppression Coils. Current-limiting Reactors. Arc Furnace Transformers. Flameproof Transformers. Machine Tool Lighting Transformers. Radio Transformers. Hand-lamp Transformers. Instrument Transformers.

SUB-STATIONS AND CONVERTING PLANT OF ALL KINDS

E.H.V. and L.V. Switchgear of all types. Automatic Switching Equipments. Fuse Gear. Mercury-Arc Rectifiers, steel-tank and steel-bulb types. Rotary Convertors. Motor Convertors. Motor-Generators. Synchronous Condensers. Frequency Changers.

ELECTRIC POWER EQUIPMENT FOR ALL INDUSTRIES

Specialists in electric drives and the complete electrification of :—Iron and Steel Works. Non-ferrous Metal Works. Arc Welding Shops. Collieries, Quarries and Mines every description. Brickyards. Cement Works. Sewage and Irrigation Works. Dockyards. Engineering Shops. Chemical Factories. Dye-works. Glass Works. Rubber Mills. Cotton, Wool, Silk and Jute Mills. Pulp and Paper Mills. Breweries. Sugar, Tea and other Food Factories. Farms and Dairies. A.C. and D.C. Motors and Control Gear in units from $\frac{1}{10}$ H.P. to 20,000 H.P. to meet all modern conditions of Starting Torque, Power Factor Correction, etc.

DOMESTIC AND ALLIED APPLIANCES

Fractional Horsepower Motors. Electric Cookers and heavy-duty Electric Cooking Equipment. Electric Fires. Electric Water Heaters. Electric Washing Machines. Small Domestic Appliances (Electric Irons, etc.). House Service Meters (Quarterly and Prepayment types).

THE ENGLISH ELECTRIC COMPANY LIMITED - STAFFORD

London Office : Queen's House, Kingsway, London, W.C.2

Printed for the Proprietors by Straker Brothers Ltd., at 194-200, Bishopsgate, London, England.